# BODY CAPACITANCE ELECTRIC FIELD POWERED DEVICE FOR HIGH VOLTAGE LINES

## CROSS-REFERENCE TO RELATED APPLICATIONS

[0001]    This application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application Ser. No. 60/490,318, "Body Capacitance Electric Field Powered AC Line Sensing System", filed July 25, 2003, and is a continuation in part under 35 U.S.C. §120 of U.S. Patent Application Serial No. 10/774,088, "Body Capacitance Electric Field Powered Device for High Voltage Lines", filed Feb. 6, 2004, both of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1.    The Field of the Invention

[0002]    The present invention relates to devices operative to be coupled to high voltage electric power lines.

### 2.    The Relevant Technology

[0003]    Typically when it is necessary for a power company to transmit electrical power over long distances, it is transmitted at relatively high voltages. These high voltages are often much higher than the voltages used by customers of the electric power. When a voltage greater than 1 kilovolt (kV) and less than 40kV is used for a particular power line, the power line is typically referred to as a distribution line. When a voltage greater than 40kV is used, the power line is typically referred to as a transmission line. Transmission lines are generally used to transmit larger amounts of power over greater distances than distribution lines.

[0004]    When a producer of electric power wants to connect to the electric grid, a connection can be made at either distribution line or transmission line level depending on the capacity of the producer's generating plant. Increasingly, due to deregulation in the power industry, the producer's generating plant is not owned by the same company as the transmission and distribution lines the plant will connect to. These types of producers are often referred to as independent power producers (IPPs). Since the power lines and the generating plant are not owned by the same company, it becomes much more important to accurately determine the amount of power the plant is feeding into the electrical grid through the transmission or distribution lines. Even when the generating plant and the power lines are owned by the same company, it is often advantageous to accurately monitor the amount of power being fed into the electrical grid.

[0005]    IPPs will often only produce power when the demand for power is such that it is economical to do so. Therefore some IPPs may only produce power for a small percentage of time during a year. When the IPP is not feeding power into the grid, its generators are normally shut down and the IPP actually draws power from the electrical grid. The amount of power drawn from the grid in this situation

is usually much smaller than when the IPP is generating power. A power usage by the IPP that is only 1/1000th of its power generation capability or less is quite possible when the plant is idle. It is often desirable that the IPP be accurately billed for the energy it consumes during idle periods and accurately compensated for energy generated during active periods.

[0006]    It is desirable for the energy meter and other instrumentation monitoring the flow of power to and from the producer to accurately measure both the power usage when the producer is idle and the power production when the producer is operating. This means that accurate energy metering and monitoring over a wide dynamic range such as 1000 times may be necessary. The energy metering and monitoring is often done at grid level voltages. Therefore, the voltage does not vary greatly (perhaps by +/-10% of its nominal value). This means that the wide variation in power flow seen by the energy metering and monitoring equipment is primarily due to the variation in current.

[0007]    An energy meter capable of measuring over a wide dynamic range of current is described in U.S. Patent Application Serial No. 10/341,079 to Hyatt et al. and entitled "Energy Device with an Extended Dynamic Range on Current Readings" which is incorporated herein by reference.

[0008]    Using an energy meter with a wide dynamic range capability for current is part of the solution for accurately monitoring the flow of power to and from a producer. Energy meters for this type of application are typically connected through external current and voltage sensors. At least the current sensors themselves should also have a wide dynamic range. Optical current sensors such as those described in the document entitled "OPTICAL TECHNOLOGY: A NEW GENERATION OF INSTRUMENT TRANSFORMER" by Klimek published in Issue 2/2003 of Electricity Today have often provided the largest dynamic range. These sensors are often mounted on large insulator stacks and weigh 100s of kilograms.

[0009]    The installation costs for sensors mounted to high voltage transmission lines may often be significant. In fact, the installation cost may be more than the cost of the sensor itself in some cases. Some of the reasons for this include the large size and weight of the sensors and the downtime that is experienced when installing, re-installing or replacing a defective sensor. Most of the weight and size of many of these sensors is the insulator used to isolate the sensor from ground and support the sensor.

[0010]    Another consideration that must be taken into account when accurately accounting for energy produced and consumed by a producer is that the instrumentation may have to be regularly calibrated to ensure accuracy. This means that the sensors may be regularly un-installed and sent for calibration while a replacement sensor is installed. This results in the install/re-install costs as well as significant shipping costs due to the weight of the sensors. This recalibration interval may be approximately every three years and the install-reinstall costs for a single sensor may be in the neighborhood of $100,000US.

[0011]    Sensors that power themselves using the magnetic field generated by the current flowing through the line they are monitoring are also available. One such device is described in U.S. Patent No. 4,799,005 to Fernandes entitled "Electrical Power Line Parameter Measurement Apparatus and Systems, Including Compact, Line-Mounted Modules". Although this device may enable decreased install-reinstall

costs, but because it is powered from the magnetic field generated by the current flowing through the line it is measuring, it may not be usable when the line current varies over a wide dynamic range. This is due to the fact that the magnetic field generated at low current may not be adequate to generate enough power to power the device or the current transformer ("CT") and associated circuitry used to power the device may be too complex or expensive to be practical.

[0012]    High voltage electric power lines criss-cross the landscape. These lines pass over waterways, valleys, highways, through and around cities, etc. They are sometimes visible to observers on the ground. They are sometimes not particularly visible to aircraft. This is especially a problem where they cross vast expanses such as over valleys or waterways where there is a long distance between support towers. Transmission line support structures are often illuminated with obstruction lights through the employment of low voltage AC mains distribution power supply means and standard red incandescent obstruction light fixtures as specified by the Federal Aviation Advisory Circular 150/5345-43E. Identification of the actual transmission line catenary wires is often limited to the suspension of passive, brightly painted spheres. These afford little aeronautical identification at nighttime or under conditions of reduced visibility.

[0013]    Recent technical advances have resulted in the ability to attach obstruction lighting directly to high voltage transmission line wires through a number of self-powering means not requiring connection to an external power source. Federal Aviation Advisory Circular AC 70/7460-1K now provides guidelines detailing the use of direct catenary wire obstruction lighting. U.S. Patent No. 5,448,138 entitled "Aeronautical obstruction light" describes a device capable of direct obstruction illumination that extracts power through magnetic coupling using a coupling coil mounted in proximity of the power line. P and R Technologies of Beaverton, Oregon, offer a number of self-powered transmission line obstruction markers. Their SpanFlash™ series of transmission line markers employ a magnetic field power supply that requires a minimum of 50 Amperes for correct operation combined with a gas discharge lighting solution. This technique does not work when transmission line currents fall below a lower limit that results in insufficient magnetic field to support adequate power generation. Many transmission lines, particularly those coming from independent power producers, experience wide operating current ranges depending on load conditions.

## BRIEF SUMMARY OF THE INVENTION

[0014]    According to one of various aspects of the invention, an apparatus couples to a power line carrying a high AC line voltage.  The apparatus has a conductive body with a body capacitance.  The apparatus further has a power supply with at least two input terminals, including a first input terminal coupled to the conductive body and a second input terminal coupled to the power line.  The power supply is coupled with electronic circuitry and converts power flow between the conductive body and the power line into a supply of power for the electronic circuitry at a voltage that is substantially lower than the high AC line voltage.

[0015]    As further described herein, the invention also has other aspects that convert power flow between a conductive body and a power line into a supply of power for electronic circuitry.  The present invention is defined by the following claims, and nothing in this summary should be taken as a limitation on those claims.  Further aspects and advantages of the invention are discussed below in conjunction with the preferred embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0016]    It is appreciated that the accompanying drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. Embodiments of the invention will be described and explained with additional specificity and detail through the use of the drawings in which:

[0017]    Figure 1 depicts a cross section of one example of a high voltage transmission line attachable device of the present invention with both mechanical and electrical elements depicted.

[0018]    Figure 2 depicts a second example of a high voltage transmission line attachable device of the present invention coupled to a power line.

[0019]    Figure 3 depicts a cross section of the second example of a high voltage transmission line attachable device of the present invention.

[0020]    Figure 4 depicts a schematic diagram of a second example of a power supply module of the present invention.

[0021]    Figure 5 depicts a schematic diagram of a third example of a power supply module of the present invention.

[0022]    Figure 6 depicts a schematic diagram of a portion of a second example of the high voltage transmission line attachable device of the present invention.

[0023]    Figure 7 depicts a third example of a high voltage transmission line attachable device of the present invention coupled to a power line.

[0024]    Figure 8 depicts a schematic diagram of the third example of a high voltage transmission line attachable device of the present invention.

[0025]    Figure 9 depicts a system utilizing the high voltage transmission line attachable devices of the present invention.

[0026]    Figure 10 depicts an electric field sensor of the present invention.

[0027]    Figure 11 depicts a cross section of the electric field sensor of Fig. 10.

[0028]    Figure 12 depicts a combined physical/electrical view of the electric field sensor of Fig. 10.


## DETAILED DESCRIPTION OF PRESENTLY PREFERRED EMBODIMENTS

[0029]    The invention relates to devices that are attachable to high voltage transmission lines and power themselves by generating a comparatively lower voltage from the current flowing between the high voltage line and the body capacitance of an element of the device. One class of devices are sensors. Sensed parameters may include current, line temperature, vibration (due to arcing, corona or other effects), strain/tension (due to ice, wind loading, conductor breakage, tower collapse, etc.), electric field (which is indicative of the steady state and transient voltage on the line), lightning detection (transient or optical), etc. Another class of devices are indicators. Indicators may include aircraft warning lights, information signs, etc. Other devices include RF transmission/reception or repeater devices (such as for use with wireless phones), radar devices, mesh networking nodes, video/audio surveillance, sound

emitting devices for scaring animals, drones that traverse the power line, etc. A common component of all these devices relates to the power supply energy source means for generating the comparatively lower voltage required for operation of the device.

[0030]    As described in greater detail herein, the voltage required for operation of the device is substantially lower than the high AC line voltage. For example, the lower voltage associated with operation of the device is typically less than 100 Vdc. In many examples, a voltage of no more than 12 Vdc is required to operate the sensors, indicators, or other electronic components used in the devices described herein. In contrast, the high AC line voltage can range, for example, from 10 kVac to over 1000 kVac. A typical transmission line has high voltage of 230 kVac line to line (three phase) or 132.8 kVac line to Earth.

[0031]    Prior art self-powered transmission line sensors, particularly for current measurement, come in a variety of forms as discussed above employing various transducer topologies and data transmission methods. Being self-powered provides an obvious benefit from an installation and high voltage ("HV") isolation standpoint. In many cases the powering energy comes from a variety of magnetic field methods whereby power is extracted through magnetic induction; typically through the use of a magnetic core and secondary winding clamped axially about the transmission line conductor. The primary difficulty with these methods is the reliance on sufficient line current required to produce sufficient magnetic field strength over some defined and wide dynamic range. At low line currents, for instance the line magnetization current of an idle IPP generating plant, it would be difficult to provide the energy required to power the sensor and its associated electronics (microprocessor, RF link, etc). If the line current is below a critical threshold then the sensor may cease to function completely. One constant is line voltage, which is generally always available. In general, when the voltage disappears in situations other than those associated with short lived transients, the line powering current also disappears and, therefore, there is no longer a need to measure many of the parameters.

[0032]    Examples of the invention make use of the fact that a metallic or other conducting body (of arbitrary shape) has a body-to-earth capacitance through which an electric current can flow. The current and resulting voltage may be electronically converted to current and voltage levels usable for electronic device energy requirements without requiring a physical connection between two high voltage potentials, which could violate conditions of desirable electrical isolation.

[0033]    The following description and figures describe various example devices that may be mounted to or form part of an electrical transmission line and derive operating power from the line. Each example device contains a power supply module generally referred to as element 108, and each variation of the power supply module is referred to as element 108a, 108b, 108c, etc. It is important to understand that each variation of the power supply module 108 may be interchangeable within the various example devices and still meet the objectives of the invention.

[0034]    Referring now to Fig. 1, a high voltage transmission line attachable device ("HVTLAD") 100 mountable as a part of a high voltage transmission line is depicted. The HVTLAD 100 includes a

cylindrical sensor body 1 that is formed from a conductive material (such as aluminum) casing having conductive end pieces 5 distributed radially and axially about a centrally located transmission conductor 10 that extends through the cylindrical sensor body 1 and beyond the conductive end pieces 5. The transmission conductor 10 is supported by and extends through two electrically insulating support bushings 15 in such a way to be mechanically connected but galvanically isolated from the electrically connected cylindrical sensor body 1 and conductive end pieces 5.

[0035]    The transmission conductor 10 further includes end piece cable clamps 20 or other means for clamping the HVTLAD 100 in line with a power line conductor and allowing mechanical and electrical connection in a power transmission line system. It is appreciated that the transmission conductor 10 and cable clamps 20 are sized appropriately for the line current, tension, and interfacing requirements of a particular transmission line installation. Inclusion of strategically located and sized conductive toroidal corona rings 30 may prevent unwanted corona discharge in areas where small radius of curvatures dictate their placement. The size of the corona rings 30 is determined by the transmission line operating voltages and they are typically included at transmission line voltages over approximately 100 kVac. These toroidal corona rings 30 may be in galvanic and mechanical contact with the cylindrical sensor body 1 and conductive end pieces 5 and, apart from their corona reducing effect, provide additional body capacitance. Additional corona shields 35 may be fitted on the two ends of the transmission conductor 10. It is appreciated that the general geometry of the complete sensor body is not limited to the cylindrical shape described but may be of other shapes. It will be appreciated that body capacitance is a function of shape as well as surface area and the preferable shape for a given application is dictated primarily by the AC line operating voltages and spacing requirements. A completely spherical metallic sensor body such as those described below may be employed with similar performance without departing from the general operation as described.

[0036]    The cylindrical sensor body 1 houses a power supply module 108a. Within the power supply module 108a, transformer T1 36 has a primary connection with Np turns connected between the transmission conductor 10 and the cylindrical sensor body 1. The cylindrical sensor body 1 is galvanically connected to the conductive end pieces 5 and toroidal corona shields 30. It is appreciated that the transmission conductor 10 is electrically isolated from the rest of the HVTLAD 100 through the insulator bushings 15 and that the transmission conductor 10 operates at high AC voltage levels with respect to earth ground. A small AC primary current Ip 37 flows through the primary winding into the cylindrical sensor body 1 as the result of the total body capacitance of the complete HVTLAD 100 and the high voltage on the transmission conductor 10. A typical high AC line voltage value ranges from 10 kV to over 1000 kVac with a typical transmission line value used for this discussion of 230 kVac line to line (three phase) or 132.8 kVac line to Earth.

[0037]    The body capacitance, with respect to the Earth surface at transmission line heights is in the picofarad ("pF") range with a typical value for this discussion being 50 pF when the cylindrical sensor body 1 is about 1 meter long and 30 centimeters in diameter. The geometry of the HVLTAD 100, combined with the sensor height above the earth ground plane and the proximity of other conductors such

as towers and other transmission conductors (other phase conductors) combine to determine the exact body capacitance. It is important to note that the exact body capacitance is not important provided that it is high enough to establish a sufficient operating primary current Ip 37 and that the reflected load impedance as presented at the primary winding of transformer T1 36 due to power supply loading is of high enough value to allow sufficient voltage division across the primary winding and effective body capacitance series connection.

[0038]    The magnitude of primary current Ip 37 is determined by the transmission line voltage applied to the transmission conductor 10 and the reactive impedance of the total body capacitance at the particular line frequency (typically 50 or 60 Hz for most transmission lines deployed throughout the world) employed. For illustrative purposes, a body capacitance of 50 pF translates to a reactive impedance of 53 Megaohms at 60 Hz. This results in a reactive primary current Ip 37 of 132.8 kVac/53e6 equaling 2.5 mA RMS. The potential difference developed across the primary winding of transformer T1 36 is small in relation to the transmission conductor 10 potential (> 132 kVac) with respect to earth ground and may be neglected in the calculation of primary current Ip 37 flow. The potential difference developed across the primary winding of transformer T1 36 (and thus the potential between the transmission conductor 10 and the body of the HVTLAD 100) is kept small in relation to the transmission conductor 10 potential due to the clamping action of an active device such as Zener diodes D1 and D2 41 as described below.

[0039]    Transformer T1 36 may be constructed using a tape wound toroidal design and may employ very low-loss core materials in order to reduce primary magnetization currents to levels below the available driving primary current Ip 37 in order to achieve usable transformer action. It may also be designed with inter-winding capacitances kept to minimal levels. Transformer T1 36 functions as a step down transformer where the ratio of Np/Ns is greater than 1. As an example, a turns ratio of 80 is used but it is appreciated that other turns ratios may be employed. Primary current Ip 37 induces a secondary current Is 40 that is rectified through diode bridge DB1 42 and charges capacitor C1 44. The negative output of diode bridge DB1 42 is connected to system ground 43, which is galvanically bonded to the shielded electronics housing 60 which is also galvanically connected to cylindrical sensor body 1. This forms the "system" ground for all electronic circuitry. In this manner the transmission conductor 10 maintains a voltage differential with respect to the cylindrical sensor body 1 equal to the primary winding voltage developed across transformer T1 36. Capacitor C1 44 voltage builds up to a level of +12Vdc, at which point, the secondary Zener diodes D1 and D2 41 clamp the secondary voltage to provide shunt regulation of the +12Vdc supply voltage 45. The Zener diode clamping action limits transformer T1 36 secondary voltage to approximately 12.7 volts peak-to-peak. Transformer T1 36, through turns ratio Np/Ns transforms the clamped secondary voltage to approximately 1200 volts peak-to-peak at the primary winding. In this manner the high primary voltage of transformer T1 36, combined with low primary current, is converted to a low voltage at higher current operable to energize sensor electronics.

[0040]    Inverter / Switcher block 46 may be provided to supply multiple outputs required by sensor electronics. It operates from the single, 12Vdc supply voltage 45. It is appreciated that other voltage

levels and combinations may be required for particular sensing applications without departing from the spirit of the invention. It is also appreciated that other secondary windings and rectifier circuitry could be added to transformer T1 36 in order to reduce the dependency on electronic switch mode voltage conversion circuitry.

[0041]     A Gas Discharge Tube 50 may be provided to limit the primary voltage of transformer T1 36 under transient line conditions due to possible lightning strikes or other short duration line events. The Gas Discharge Tube 50 is characterized by having low inter-electrode capacitance (typically 1 pF), which is advantageous in order to prevent the diversion of body capacitive current from the transformer primary winding. It will be appreciated that other types of transient suppression devices may also be used.

[0042]     A current transducer 65 is shown coupled to the transmission conductor 10. The current transducer 65 may have wide dynamic range covering from 100 mA RMS to over 2000 Arms (in the example although many other current ranges are possible). Suitable current sensing topologies include traditional toroidal magnetic core types, actively compensated zero flux types (active CTs), Hall effect, optical current transducers (a component of optical CTs), and Rogowski coils with each having certain advantages or disadvantages including accuracy, cost, weight, dynamic range, and useable bandwidth. An actively compensated core type may be employed when the high accuracy is required for revenue applications. A Rogowski coil may be employed when a high current dynamic range and/or high bandwidth is required for certain protective applications.

[0043]     The output of the current transducer 65 is an analog signal that may require amplification and signal conditioning performed by the analog circuitry 66. This module may include selectable analog gain blocks under auto-ranging processor control. The analog output of the analog circuitry 66 may be connected to the Alias Filter and A/D module 67 which removes frequency components above ½ the sampling or Nyquist rate. The A/D converter digitizes the analog signal at the sample rate (for example 256 samples / second) and provides the digital information to the Processor module 68. The Processor Module 68 controls the analog circuitry 66 and Alias Filter and A/D Conversion 67 modules while processing and packetizing the A/D samples stream. The processor module 68 communicates with the RF data link transceiver 69, which is used to transmit the acquired current waveform to the coupled ground based receiver (not shown) where the waveform may be processed for power measurement or power quality information. The RF data link transceiver 69 may operate at VHF and higher frequencies and employ a robust modulation and error correction method to provide reliable and secure telemetry data in real time. In addition, the RF data link transceiver 69 and/or processor module 68 may implement encryption and/or authentication schemes to make it difficult to tamper with the data being transmitted and/or received.

[0044]     The RF data link transceiver 69 is coupled to the antenna 76 through a reactive matching network 75 formed from L1 and C2. The purpose of matching network 75 is to effectively impedance match the output of the RF data link transceiver 69 to the antenna 76 and maintain the DC or low frequency potential of the exposed antenna 76 at the potential of the shielded electronics housing 60. Other inductances, capacitances, transmission line stubs, and/or transformer matching circuitry may be

used to achieve similar functionality. The circuitry shown 75 is essentially a high pass filter with inductor L1 75 maintaining the zero DC and low frequency (50/60 Hz) potential of the antenna 76 with respect to the shielded electronics housing 60 common potential.

[0045]    Cylindrical sensor body 1 may be split vertically into two separate sections that are insulated from one another. The first section may be used as previously described to derive operating power for the device. The second section may be used to sense the voltage on the transmission conductor 10 by monitoring current flow from the transmission conductor 10 to the body capacitance of the second section. A second transducer may thus be provided to supply an analog signal indicative of voltage in transmission conductor to analog circuitry 66. In this manner, processor 68 may directly calculate power parameters such as watts flowing through the transmission conductor due to the local availability of both current and voltage signal information before transmitting the data. Additionally, it may be possible to derive the voltage on the transmission conductor 10 by monitoring the primary current Ip 37 flow and using appropriate signal processing without the addition of the second section.

[0046]    Additional transducers may also be interfaced to processor 68 and powered by inverter/switcher block 46. These additional transducers may include vibration, tension, temperature (both for the conductor and ambient temperature), lightning detector and other types of transducers.

[0047]    Instead of using an RF data link transceiver 69, an RF transmitter may be used. In addition, the RF data link transceiver 69 may be replaced with a laser, fiber optic or other optical data transceiver or transmitter. This has the advantage of being extremely directional and therefore it is much more difficult to jam or tamper with the signal. RF has the advantage of being less susceptible to obstructions such as airborne particulates, fog, or objects physically blocking the signal path.

[0048]    Processor 68 may be equipped for reception of an accurate time base. This time base may come from the RF data link transceiver 69 or may come from a separate time source such as a global positioning system (GPS) receiver. These may include a disciplined phase locked master clock oscillator. This allows the processor 68 to accurately timestamp the time of conversion of the A/D sample data that is to be transmitted through the RF data link transceiver 69. In addition, A/D sampling may be synchronized to the time source such that for instance sampling may start at a given time boundary (such as even second). This allows the accurate computation of power parameters (such as kW, kVAR, kVA, power factor, symmetrical components, etc.) by the ground based transceiver or computer/intelligent electronic device attached thereto. It also allows for comparison of phase calculations resulting from the sampling of multiple HVTLADs 100. A GPS receiver may also provide the location of the HVTLAD 100 to the processor 68. The location of the HVTLAD 100 may be transmitted through the RF data link transceiver 69 to a remote device, such as a computer, that is not physically coupled with the HVTLAD 100. The location may include the elevation of the sensor which may be useful in detecting transmission line sag due to broken insulators, overheated conductors, etc. Alternatively, the HVTLAD may comprise a radar or other altimeter for elevation determination. In addition, the location may include longitude and latitude information which may ease commissioning costs due to the fact that the location of the HVTLAD can be correlated with the expected location at the remote device. For instance, it may not be

strictly necessary to record the location that any given HVTLAD is installed since the HVTLAD can transmit its location and other configuration information to a remote device. This may be valuable when determining grid stability as described below.

[0049]     HVTLAD 100 may be constructed in "clamp-on" form. In this case, transmission conductor 10 is the transmission line of a power system. Cylindrical sensor body 1 may be constructed in a manner operable to split horizontally as oriented in Fig. 1 and may be placed over the transmission line and clamped together. In this case, cable clamps 20 and additional corona shields 35 may not be provided.

[0050]     Referring now to Fig. 2, a second example of the HVTLAD 100 is shown. This example of the HVTLAD 100 includes three component sections; an electric field energy source 102, overhead wire conductive support tube 107, and electronic obstruction light beacon module 104.

[0051]     The electric field energy source 102 includes a conductive sphere 106, preferably made with aluminum or other electrically conductive material, and a tubular conductive support tube 107 that extends through the conductive sphere 106, and is coupled to both ends of the conductive sphere 106 through insulators 188. The conductive support tube 107 is therefore galvanically isolated from the conductive sphere 106. It is appreciated that the conductive support tube 107 is at the high electric potential of the transmission line 105 to which the complete HVTLAD 100 is attached through a clamp 110 or other attachment means which makes electrical and mechanical contact with the transmission line 105. Variations of the clamp 110 as depicted in the Figures 2, 3 and 8, may be required for affixing the HVTLAD 100 to varying transmission line cable sizes and configurations including single, dual, and quad high voltage line configurations. A curved feature 114 of the conductive support tube 107 allows positioning of the HVTLAD 100 directly over and centered on the transmission line 105 wire (s) in order to reduce the rotational torque applied by the clamp 110.

[0052]     Referring now to Fig. 3, the electric field energy source 102 further includes a power supply module 108 mounted to the conductive support tube 107 within the conductive sphere 106. Input connection to the power supply module is provided through wire connection 112 made to the galvanically isolated conductive sphere 106 and a second wire connection 109 made to the conductive support tube 107 that allows the power supply module to be coupled to the transmission line 105 through the conductive support tube 107 and clamp 110. The power supply module 108 common or effective "ground" connection is made through the second wire connection 109. The positive DC output is provided to a multi-conductor wire cable 111 that is routed through the conductive support tube 107 to the electronic obstruction light beacon module 104. The multi-conductor wire cable 111 may additionally carry a serial communications link connection 138 between the power supply microcontroller U1 130 and the obstruction light controller 150. The conductive support tube 107 provides the negative or circuit common "ground" return path through second wire connection 109.

[0053]     It will be appreciated that many modifications of the location of the various components in the HVTLAD 100 are possible without departing from the spirit and scope of the invention. For instance, in this example, power supply module 108 may be placed within electronic obstruction light beacon

module 104 with appropriate wire connection(s) to conductive sphere 106 through conductive support tube 107.

[0054]    Two examples of the power supply module 108b, 108c within the conductive sphere 106 are presented. The first embodiment utilizes a magnetically coupled technique while the second embodiment employs a switch-mode flyback topology. In both examples, the power supply module 108 functions to convert the low level capacitive reactive AC current flowing between the high voltage transmission line 105 and the galvanically isolated conductive sphere 106 into a low voltage +12Vdc supply voltage 45 of higher current capability suitable for powering the electronic obstruction light beacon module 104 and power supply module 108 electronics. The power supply module 108 may provide +12Vdc with a continuous power level of 1.3 watts when connected to a 230 kV ac transmission line. Higher line voltages result in increased power availability. A 740 kV ac transmission line may produce in excess of 4 watts of continuous power availability when utilizing a conductive sphere 106 of 1 meter in diameter having a free space capacitance of approximately 50 pF as defined by equation:

$$C = 4 \cdot \pi \cdot E_o \cdot r,$$

where C=capacitance in Farads, $E_o = 8.85 \times 10^{-12}$ $C^2/(N*m^2)$, and r=the radius of the sphere in meters.

[0055]    Referring now to Fig. 4, a second example of the power supply module 108b is shown. Transformer T1 36 has a primary connection with Np turns connected between the conductive support tube 107 and the galvanically isolated conductive sphere 106. It is appreciated that the conductive support tube 107 is additionally galvanically coupled to the transmission line 105 through a clamp 110. A small AC primary current Ip 37 flows through the primary winding into the conductive sphere 106 as the result of the total body or "free space" capacitance of the conductive sphere 106 and the high voltage transmission line 105 potential. A typical high AC line voltage value ranges from 10 kV to over 1000 kVac with a typical transmission line value used for this discussion being 230 kVac line to line or 132.8 kVac line to neutral (earth) potential. The conductive sphere 106 capacitance at transmission line heights is in the picofarad range with a typical value for this discussion being approximately 50 pF for a conductive sphere 106 of three feet in diameter. The limiting lower value of "free space" capacitance for a conductive sphere is provided by the equation shown above with capacitance being proportional to the radius of the conductive sphere. The conductive sphere 106 capacitance, as "seen" by the transmission line 105 and the connected and energized conductive support tube 107, has a lower "free space" limit established by the equation, but is also affected by the height above the earth ground plane and the proximity of other conductors such as towers and other transmission conductors.

[0056]    It is important to note that the exact capacitance of the conductive sphere 106 is not particularly important provided that it is high enough to establish a sufficient operating primary current Ip 37 and that the reflected load impedance as presented at the primary winding of transformer T1 36, due to power supply loading, is of high enough value to allow sufficient voltage division across the primary winding of transformer T1 36 winding and conductive sphere 106 effective capacitance series connection.

Higher or lower power levels may simply be achieved by adjusting the size and therefore capacitance, of the conductive sphere 106.

[0057]    The electric field energy source 102 body geometry is not limited to spherical shapes but may include other geometries such as toroidal, cylindrical and planar topologies or combinations thereof. In Fig. 2, the electric field energy source 102 is shown hanging below the transmission line 105 wire(s) but may also be located in other positions or electrically combined in parallel with other conductive bodies in order to increase total body capacitance and power generation capability. The electric field energy source 102 may also be of tubular shape, positioned coaxially either completely or partially around but insulated from the transmission line 105 wire(s) as shown in Fig. 1. The selection of the geometry of the electric field energy source 102 at high transmission line potentials is normally be influenced more by attempting to prevent corona discharge and radio interference through the use of sufficient radii of curvature in order to reduce electric field intensities to non-ionizing levels. A three foot diameter conductive sphere 106 mounted below the catenary transmission line wire(s) as shown in Fig. 2 may provide sufficient capacitance and corona rejection for up to 500 kV line to line potentials while additionally providing a passive visual Federal Aviation Administration painted (orange and white) obstruction marker.

[0058]    The magnitude of primary current Ip 37 is determined by the transmission line voltage applied to the conductive support tube 107 and the reactive impedance provided by the total body capacitance on the conductive sphere 106 at the particular line frequency (typically 50 or 60 Hz) employed. For illustrative purposes, a body capacitance of 50 pF translates to a reactive impedance of -j53 Megohms at 60 Hz. This results in a reactive primary current Ip 21 of 132.8 kVac/-j53e6 equaling j2.5 mA RMS. The potential difference developed across the primary winding of transformer T1 36 is small in relation to the conductive support tube 107 potential (> 132 kVac) and therefore may be neglected in the estimation of primary current Ip 37 flow. The potential difference developed across the primary winding of transformer T1 36 (and thus the potential between the conductive sphere 106 and the rest of the body of the HVTLAD 100) is kept small in relation to the transmission line 105 potential due to the clamping action of an active device such as Zener diodes D1 and D2 41 as described below.

[0059]    In order to reduce primary magnetization current to a level significantly below the available driving primary current Ip 37 it may be necessary to use a transformer T1 36 incorporating a tape wound toroidal design employing low-loss magnetic core material to achieve useable transformer action. Conventional silicon-steel power transformers suffer from core losses that may result in magnetization current well above the available driving primary current Ip 37 source. A representative transformer may be wound on a Magnetics Incorporated 50100-4F Supermalloy™ toroidal tape wound core. Other low loss core materials; such as MetGlas™ and Permalloy™ may be used, particularly at higher transmission line voltages which translate into higher driving primary current Ip 37 levels. Transformer T1 36 functions in the step down configuration where the ratio of Np/Ns is greater than 1. As an example, a turns ratio of 80, with 10,000 primary turns and 125 secondary turns, may used but it is appreciated that other turns ratios may be employed to obtain different output voltage levels and current levels. A high number of primary turns is employed on the primary winding of transformer T1 36 in order to

simultaneously support a high primary voltage, a flux level optimized for low core loss, and a small magnetic core cross section.

[0060]    Primary current Ip 37 induces a secondary current Is 40 that is rectified through diode bridge DB1 42 and charges capacitor C1 44. The negative output of diode bridge DB1 42 is connected to system ground 43, which is galvanically bonded to the conductive support tube 107 through second wire connection 109. This forms the "system" ground for all electronic circuitry in both the power supply module 108b and electronic obstruction light beacon module 104. In this manner the conductive support tube 107 maintains a voltage differential with respect to the conductive sphere 106 equal to the primary winding voltage developed across transformer T1 36. Capacitor C1 44 voltage builds up to a level of +12.7Vdc, at which point the secondary 12 Volt Zener diodes D1 and D2 41 clamp the secondary AC voltage to provide shunt regulation of the +12Vdc supply voltage 45. The Zener diode clamping action limits transformer T1 36 secondary AC voltage to approximately 12.7 volts peak-to-peak of clipped sinusoidal waveshape. Transformer T1 36, through turns ratio Np/Ns transforms the clamped secondary voltage to approximately 1016 volts peak-to-peak across the primary winding. In this manner the high primary voltage of transformer T1 36, combined with low primary current Ip 37, through transformer action, is converted to a lower secondary voltage at higher secondary current Is 40 levels operable to power additional power supply module 108b and electronic obstruction light beacon module 104 electronics. Zener diodes D1 and D2 41 are of the power variety as they must be able to dissipate the full power supply output when the power supply module 108b is unloaded. Diode Bridge DB1 42 utilizes Schottky diodes in order to minimize diode potential drops and maximize system efficiency. A Gas Discharge Tube 50 may be provided to limit the primary voltage of transformer T1 36 under transient line conditions due to possible lightning strikes or other short duration line events. Alternatively other types of transient suppression devices may be used. It is appreciated that other power supply configurations are possible including using different turns ratios, clamping voltages means, multiple secondary output windings and configurations and various other component substitutions without departing from the spirit of the invention.

[0061]    The remaining power supply module 108b circuitry is provided for storage of energy and communication of energy data to the electronic obstruction light beacon module 104. The +12Vdc supply voltage 45 is reduced to 5Vdc through regulator 127 to power microcontroller U1 130 having internal RAM, ROM, A/D, Digital I/O, and communications ports. Diode D3 and 1 Farad (or other value) capacitor C2 128 provide the microcontroller U1 130 with +12Vdc supply voltage 45 outage "ride-through" capability allowing continuous control operation during load fault and transient events associated with high energy capacitor bank 132 and battery 135 charging. A Hall effect or other DC current sensor 129 provides power supply current data to microcontroller U1 130. Resistive divider R1 and R2 131 divides the +12Vdc supply voltage 45 providing voltage level information to the A/D input channel of microcontroller U1 130. The power supply module 108b is additionally provided with a backup battery 135, charge control 133 and activation switch 136 all operating under microcontroller U1 130 management. The backup battery 135 provides continuous electronic obstruction light beacon

module 104 power under conditions of transmission line 105 voltage sag or failure. Alternatively a super capacitor or other energy storage device may be used instead of backup battery 135.

[0062]    The power supply module 108b may additionally include a high energy capacitor bank 132 having a combined total capacitance of 8.3 Farads which translates into 600 joules of energy storage at the supply level of +12Vdc supply voltage 45. This high level of energy storage can be used for short term backup power in the event of transmission line 105 voltage sag or failure. The low impedance level afforded by the high energy capacitor bank 132 additionally provides high peak power reservoir capacity suited for intermittent (such as required for a flashing LED beacon array) high peak energy demand applications. Capacitors having values in the 0.1 to 50 Farad range combined with low effective series resistance suitable for high energy discharge rates are a relatively new technology. Representative types include the Cooper Industries Aerogel™ 50 Farad, 2.5 volt capacitor, part number B1840-2R5506 and, for even higher energy storage, the Maxwell Technologies BCAP0013 450 Farad, 2.5 volt capacitor.

[0063]    Microcontroller U1 130 provides charge control of the high-energy capacitor bank 132 through field effect transistor ("FET") switches Q1, Q2, and Q3 of FET bank 134. When not charged, the high-energy capacitor bank 132 may appear as a low impedance short circuit which may require controlled charging particularly when the driving +12Vdc supply voltage 45 has limited current capability. Microcontroller U1, 130 through current (by DC current sensor 129) and voltage (by resistive divider R1 and R2 131) measurement determines, in real time, the available supply current that may be safely directed to charging the high-energy capacitor bank 132 without causing a significant voltage loss in +12Vdc supply voltage 45 or detrimental transient condition. Resistors R3 and R4 140, through FET switches Q1 and Q2 of FET bank 134 provide a means of variable rate charging depending on the calculated available supply current. FET switch Q3 of FET bank 134 is turned on after the high-energy capacitor bank is fully charged effectively placing a low impedance between capacitor bank 132 and system ground 43. Capacitor bank is then capable of providing short term high peak power capability. A serial communications link 138 is provided to allow energy data and control information to be passed between the power supply module microcontroller U1 130 and the obstruction light microcontroller U2 171 (Fig. 6). Battery 135 charge information, supply current (measured by DC current sensor 129), +12Vdc supply voltage 45, and supply module temperature from temperature sensor 141 may be transmitted via the RF data link transceiver 69 to a remote location for alarm and diagnostic purposes. Detection of transmission line 105 voltage failure is also possible by monitoring Isense supply current (through DC current sensor 129). If it drops to zero or reverses direction as the result of powering current for the microcontroller U1 130 flowing from the energy storage means instead of the transformer T1 36 then a transmission voltage failure is indicated and this status may be forwarded via the RF data link transceiver 69.

[0064]    Referring now to Fig. 5, a third example of the power supply module 108c is shown. A small AC primary current Ip 37 flows through diode bridge rectifier DB2 150 charging capacitor C3 151. AC primary current Ip 37 flows as the result of the total body or "free space" capacitance of the galvancially isolated conductive sphere 106 and the high voltage transmission line 105 potential in a manner similar to

that detailed in the previous examples of the power supply module 108. The DC voltage developed across capacitor C3 151 increases to approximately +1000 Vdc on high voltage dc supply 153 at which time high voltage Zener diodes D4 and D5 152 clamp the AC input voltage effectively limiting the maximum dc switch-mode supply input voltage to +1000 Vdc. The potential difference developed across the high voltage Zener diodes D4 and D5 152 (and thus the potential between the conductive sphere 106 and the rest of the body of the HVTLAD 100) is kept small in relation to the transmission line 105 potential due to the clamping action of the high voltage Zener diodes D4 and D5 152.

[0065]    Bootstrap circuitry 154 initially provides startup power for the switch-mode controller 155, reverting to a high impedance state after transformer switching action successfully begins providing low voltage output 163. MOSFET Q4 is initially biased into conduction through a positive gate to source potential provided by Zener diode D6 and resistor R6. Switch-mode controller 155 supply filter capacitor C4 156 is charged through Q4 and R5 until a low voltage threshold is reached at which point the switch-mode controller 155 begins switching action. Capacitor C4 156 stores energy to provide sufficient startup time until switch-mode action provides operating voltage through the auxiliary power winding 157 of flyback transformer T2 158 and rectifier D7 159.

[0066]    After a finite start-up time the low voltage output 163 stabilizes and switch-mode controller 155 pulls the gate voltage of MOSFET Q4 low which effectively removes the bootstrap circuitry 154 from loading the high voltage dc supply 153 line. Resistor R6 remains in circuit but is of high value as to limit power consumption. The topology shown is representative of the flyback switch-mode method of dc-to-dc conversion. High voltage MOSFET Q5 160 is turned fully on or off at a high switching frequency (greater than 10 KHz) in response to voltage and current feedback signals in order to regulate the +12Vdc supply voltage 45. Flyback transformer T2 158 primary winding 161 is switched directly across the high voltage input when high voltage MOSFET Q5 160 is turned on. Current linearly ramps up in the primary winding storing an amount of magnetic energy per cycle defined by the equation: $E = \frac{1}{2} \cdot Lp \cdot Ipk^2$, where Lp is the primary inductance and Ipk is the peak primary current.

[0067]    When high voltage MOSFET Q5 160 is turned off, the secondary windings (auxiliary power winding 157 and secondary winding 162) commutate or "flyback" and return the stored energy into filter capacitor C4 156 and capacitor C1 44 through rectifiers D7 and D6 168, respectively. This switch-mode action repeats at a high frequency, which allows the use of small, and inexpensive low loss ferrite cores for flyback transformer T2 158. Switching action is regulated on a cycle-by-cycle basis with control provided by the switch-mode controller 155 such that the +12Vdc supply voltage 45 is maintained at a constant value. Switching action control, on a cycle-by-cycle basis, is provided by comparing the feedback line 164 to an internal reference combined with monitoring of Ipk 165. If the feedback line 164 exceeds the internal threshold then switching action is terminated. Feedback is provided by auxiliary power winding 157 rectified output. Switching action is also terminated on a cycle-by-cycle basis if Ipk 165 of primary winding 161 exceeds a preset level resulting from the voltage developed across resistor R7 166. A snubber RC diode network 167 is provided to reduce transformer T2 primary winding 161 voltage switching peaks in order to prevent damage of high voltage MOSFET Q5 160. The described

switch-mode power supply represents the "flyback" topology. It is appreciated that other switch-mode topologies may be employed to reduce the high dc voltage supply 153 down to a lower +12Vdc supply voltage 45 compatible with solid-state electronics including forward mode buck, push-pull, half-bridge, and full bridge conversion. The remaining power supply module 108c circuitry including microcontroller, energy storage, and communications means functions similarly as previously described in the second example of the power supply module 108b.

[0068]    Referring now to Fig. 6, the electronic obstruction light beacon module 104 is shown. The electronic obstruction light beacon module 104 electronics are housed in a conductive metallic enclosure 176, which is galvanically and mechanically coupled to the conductive support tube 107 and bonded 181 to system ground 43. Power for the electronic obstruction light beacon module 104 is provided by the power supply module 108 through multi-conductor wire cable 111. Multi-conductor wire cable 111 is routed through the conductive support tube 107. The low voltage +12Vdc supply voltage 45 provides power for the electronic obstruction light beacon module 104. Microcontroller U2 171 operates on +5Vdc derived from the +12Vdc supply voltage 45 and a 5V regulator 180. This allows continued operation under decreasing +12Vdc supply voltage 45 levels as the result of transmission line 105 voltage loss. Note that the +12Vdc supply voltage 45 level is maintained by the high energy capacitor bank 132 and/or battery 135 combination under conditions of transmission line 105 loss. It is appreciated that, under conditions of transmission line 105 loss, the +12Vdc supply voltage 45 level decays at a rate determined by the effective load impedance and energy capacity of the high energy capacitor bank 132 and/or battery 135 combination.

[0069]    A series string of light emitting diodes (LEDs) 182 provides a high intensity, long life, solid-state light source, the output of which may be optically diffused through the employment of a polycarbonate lens system 170. Alternatively other types of light emitting devices such as incandescent lamps, fluorescent lamps, etc. may be used. The polycarbonate lens system distributes the light substantially uniformly about approximately 360 degrees in azimuth and 90 degrees in elevation (from horizontal) in order to provide aeronautical visibility from all approach vectors. The series configuration of LEDs 182 is used to provide matched individual LED current which translates to uniform individual LED brightness. The series LEDs 182 are shown having five individual LEDs 182 in each bank. It is appreciated that configurations having more or less LEDs 182 can easily be accommodated through adjustment of the driving potential source levels. Two similar, high efficiency switch-mode constant current boost converters 183 are utilized to drive each string of series LEDs 182 with output drive 184 controlled in an on-off fashion through digital output 185 of micro-controller U2 171. Resistors R8 and R9 186 provide micro-controller U2 171 with an analog signal representative of the individual current in each string of series LEDs 182 which in turn provides an indication of LED functionality for diagnostic and alarm purposes. Having two separate LED light sources provides a degree of redundancy should an individual string of series LEDs 182 or constant current boost converter 183 fail.

[0070]    An ambient light sensor 177 provides micro-controller U2 171 with ambient light condition data in order to make programmed light flash and intensity visibility adjustments.

[0071]    A GPS receiver module 173 combined with GPS antenna 172 provides accurate time-of-day information through a serial data channel 199 to micro-controller U2 171. This information may be used by micro-controller U2 171 to accurately time synchronize flashing of multiple electronic obstruction light beacon modules 104 in order to provide enhanced visibility of a lighted transmission line section. Time-of-day synchronization may also be used to vary flash patterns and/or intensities to accommodate day or night conditions. The GPS receiver module 173 may also provide an accurate high frequency clock 193 to the micro-controller U2 171. This may be used as the operating clock for the micro-controller U2 171. Alternatively, other types of time synchronization reception circuitry may be utilized to provide a time based to micro-controller U2 171 for flash synchronization.

[0072]    RF data link transceiver 69, combined with antenna 76, provides a full duplex communications link between the micro-controller U2 171 and a control/monitoring station or other obstruction light(s). RF data link transceiver 69 may, for example, be a 900MHz secure data transceiver. This communications link provides a means of remote alarm and diagnostic monitoring combined with program upload capability. It additionally provides for communications between multiple electronic obstruction light beacon modules 104 for flash synchronization purposes.

[0073]    Flash time synchronization of multiple obstruction lights may be completely user specified in order to allow unique simultaneous or sequential strobe flashing combined with individually programmed flash rates and duty-cycles.

[0074]    High pass filter elements 189 and 190 function to protect the input circuitry of the GPS receiver module 173 and RF data link transceiver 69 from DC and low frequency signals (such as 50 or 60Hz) that may arise due to the high electric field potentials that exist in the proximity of the antenna elements. Low frequency and DC components are effectively "shunted" to the conductive metallic enclosure 176, which in turn is connected to the system ground 43 while allowing the desired on channel frequency components to pass with little attenuation. The high pass filter elements 189 and 190 may utilize passive inductive, capacitive, and transmission line components.

[0075]    Conductive toroidal ring 191 (Fig. 2) functions to reduce and displace the electric field intensities about the conductive metallic enclosure 176 and peripheral attachments including the GPS antenna 172, antenna 76, polycarbonate lens system 170, and ambient light sensor 177.

[0076]    Referring now to Fig. 7, another example of the HVTLAD 100 is shown. This example includes a measurement module 750 and a current sensor 805. The current sensor may be an active CT, a passive CT, a Rogowski coil, an optical CT, a Hall effect device, etc. The current sensor 805 senses the current flowing in a high voltage current carrying conductor 810 (such as a transmission line). The measurement module 750 includes electronics for measuring parameters such as voltage, current and temperature. This example of the HVTLAD 100 includes additional components described previously with respect to other examples of the HVTLAD 100.

[0077]    Referring now to Fig. 8, a combination electrical/mechanical block diagram of the measurement module 750 is shown. Some elements of the measurement module 750 are similar to those of the electronic obstruction light beacon module 104 therefore only differences are described hereafter.

[0078]    The measurement module 750 includes a metallic (or other conductive material) plate 740 which is insulated by insulators 735 from the conductive metallic enclosure 176. In the illustrated example, the metallic plate 740 is in the form of a dome, although this is not necessary. A first inherent capacitance 710 is formed between the metallic plate 740 and the conductive metallic enclosure 176. A second inherent capacitance 705 is formed between the metallic plate 740 and the environment in a similar fashion as the conductive sphere 106 described previously. Resistor R20 720 is connected to the metallic plate 740 and in conjunction with resistor R21 715 forms a resistive divider capable of feeding an analog signal indicative of the voltage on metallic plate 740 to amplification circuitry 730. Amplification circuitry 730 feeds a scaled version of this voltage to an A/D input of microcontroller U2 171. This voltage is indicative of the voltage on high voltage current carrying conductor 810 due to the fact that inherent capacitances 705 and 710 form a capacitive divider between the conductive metallic enclosure 176 and an external reference such as ground or another phase conductor. Metallic (or other conductive material) electric field shields 755 in contact with conductive metallic enclosure 176 may be provided to shield the metallic plate 740 from stray electric fields.

[0079]    Signal(s) indicative of current in the high voltage current carrying conductor are fed from the current sensor 805 to the amplification circuitry 725 through line 745 which passes through multi-conductor wire cable 111. The output of amplification circuitry 725 is fed to an A/D input of microcontroller U2 171.

[0080]    Microcontroller U2 171 samples the signals from amplification circuitry 725 and 730. These signals are indicative of voltage and current in the high voltage current carrying conductor 810. The microcontroller U2 171 may timestamp these samples using time indications received from GPS receiver module 173 and transmit the timestamped signals to a receiving device through RF data link transceiver 69. In addition, microcontroller U2 171 may make power calculations directly using the samples and transmit the results of these calculations through RF data link transceiver 69. Some of the results of the power calculations may include power parameters such as rms current, rms voltage, watts, VARs, VAs, frequency, harmonics, phasors, etc.

[0081]    During initialization, the microcontroller may also transmit appropriate calibration constants through RF data link transceiver 69 to a receiving device. This is so the receiving device can make accurate power calculations based on the samples if the samples are not individually calibrated by microcontroller U2 171.

[0082]    Referring now to Fig. 9 an example grid stability monitoring system incorporating the HVTLAD 100 is shown. Various transmission lines 905 form a portion of an electric grid 900. As known in the art, the remainder of the grid 910 consists of many transmission lines, distribution lines, transformers, substations, generators, loads and other electrical equipment (not shown). The transmission

lines 905 serve to interconnect various parts of the grid. Various HVTLADs 100 are installed on the different transmission lines 905 and at different points on the same transmission lines 905. The HVTLADs 100 transmit voltage and/or current information to local receiving stations 920 over wireless links 921. The local receiving stations 920 in turn communicate at least one of voltage, voltage phase information, current, current phase information, power, frequency, etc. to a monitoring station 930 over communication links 931.

[0083] A number of factors may be considered when analyzing the stability of an electrical grid. One factor is voltage. In general, the closer the voltage at every given point in the grid is to the expected nominal voltage, the more stable the grid is. A second factor is voltage phase. In general, it is desirable to keep the relative voltage phase of all points in the transmission grid to within about 60-70 degrees of one another. In addition, if a discontinuity in voltage phase is detected, this may be an indication of grid instability. A third factor is frequency. In general, the closer the frequency at a given point in the transmission grid is to other points within the grid, the more stable the grid is. In the system shown in Fig. 9, due to the fact that the monitoring station 930 can receive at least one of these indications from the various HVTLADs 100 and these indications are accurately timestamped or time synchronized as described above, grid stability can be analyzed by either a user or a computer system within the monitoring station 930. This may be done by display of the information from the HVTLADs 100 on a display in the monitoring station 930 and/or analysis within the computer system. An indication of grid stability is thus attained and if the grid is not sufficiently stable, mitigation activities can either manually or automatically be undertaken. As described above, each HVTLAD 100 may have a GPS receiver module 173 which provides position information. Alternatively, the HVTLAD 100 may have another type of RF based positioning and/or time synchronization receiver. By correlating this position information with information on where particular elements of the electrical grid 900 are located, the installation location of any given HVTLAD 100 may be determined without having to record the position of the HVTLAD 100 during installation. In addition, with position information from multiple HVTLADs 100 in the grid, a map of the grid including, the voltage, current, frequency, phase, etc. can be developed and/or displayed in the monitoring station 930. The monitoring station 930 may not necessarily be operated by the same company or entity that owns the transmission grid itself.

[0084] Multiple HVTLADs 100 on a transmission line 905 may also be used for fault detection and/or location. Using the voltage and current samples taken by each HVTLAD 100, the HVTLAD 100, local receiving stations 920 or monitoring station 930 can calculate the impedance of the line seen by the HVTLAD 100 at each point on the transmission line 905. This information can be used to triangulate the location of a fault or determine that power is flowing through an unexpected path. Alternatively, or in addition, analysis of the waveforms of voltage and or current seen by each HVTLAD 100 can be used for fault detection and/or location.

[0085] Having multiple HVTLADs 100 at various points on the transmission lines 905 of the electric grid 900 allows for the detection of congestion in the electrical grid 900. For instance if a transmission line 905 is nearing its capacity, the price charged for use of that transmission line 905 by a producer or

consumer of electricity may be increased. Alternatively or in addition, this information may be used to reroute power flow through a different path in the electrical grid. In a similar manner, if electricity flow is below the capacity of a given transmission line 905 by a given amount, the price charged for use of that transmission line 905 may be decreased or additional flow may be routed to that transmission line 905. This functionality may be particularly valuable in a deregulated utility environment where the owners of the transmission lines 905 may not be the same as the owners of the generation facilities connected to the transmission lines 905.

[0086]    The antenna 76 on the HVTLAD 100 and/or the antenna in the local receiving stations 920 may be of directional type to reduce the likelihood of interference or tampering with the RF link between the two. A directional antenna focuses radio frequency energy emanating from said radio frequency transmitter. In addition, the shape of the HVTLAD 100 and/or position of corona rings 30, 191 of the HVTLAD may also serve to shield antenna 76 from extraneous RF energy and prevent RF energy from the antenna 76 from propagating in certain directions.

[0087]    Fig. 10 shows an electric field sensor 1006 capable of providing an accurate measurement of the high voltage current carrying conductor 810 voltage. The electric field sensor 1006 may be an alternative to elements 705, 710, 715, 720, 730, 735, 740, and 755 of Fig. 8 and may be separately mountable on the high voltage current carrying conductor 810. The electric field sensor 1006 is formed from a conductive cylinder 1002 having two conductive toroidal rings 1003 affixed to both ends of the conductive cylinder 1002. Both the conductive cylinder 1002 and conductive toroidal rings 1003 may be formed of lightweight materials such as aluminum. The toroidal rings 1003 are in galvanic contact with the conductive cylinder 1002 and are sized to prevent the formation of localized corona discharge at the high voltage current carrying conductor 810 voltages encountered in operation. A transmission line clamp 1005 provides mechanical and galvanic connection to the transmission line 810 and is mechanically adjustable to allow full electric field sensor 1006 positioning in both elevation and azimuth. This feature provides the ability to effectively "aim" the electric field sensor 1006 in order to avoid the effect of undesirable electric field sources such as those generated by an additional conductor phase(s). A dielectric cover 1001 (formed of a material such as polycarbonate) at one end of the electric field sensor 1006 functions to provide environmental protection of the internal electronics while simultaneously allowing the electric field to capacitively interact with an internal conductive sense disk 1101 (Fig. 11).

[0088]    Figure 11 shows the electric field sensor 1006 in cross section. The conductive sense disk 1101 (or plate) is mechanically supported and galvanically isolated by insulator bushing 1102. An axially aligned wire connection 1103 is supported within the insulator bushing 1102 and functions to provide a low impedance connection between the conductive sense disk 1101 and electric field sensor electronics 1200 (Fig. 12). The electric field sensor 1006 may be divided into two compartments by conductive partition 1104 functioning to prevent internally generated electric fields from undesirably coupling to the conductive sense disk 1101. Conductive removable end plate 1106 (which may be formed of aluminum) provides access to the sensor electronics 1200. The complete electric field sensor 1006 is therefore sealed from the external environment as is required for long term outdoor, transmission line mounted operation.

Connector J1 1004 provides sensor power, control input, and analog signal output between the electric field sensor 1006 and measurement module 750 (Fig 7) and would essentially replace the fixed position electric field sensor 740. It is appreciated that the electric field sensor 1006 is described as a separate sensing unit having the ability to be positioned or "aimed" independently of the electric field energy source 102 (Fig 7) and measurement module 750 (Fig 7). It is also feasible to integrate the electric field sensor 1006 directly into a single structure combining current measurement, electric field measurement, signal processing, data transmission, and power generation.

[0089]     Figure 12 combines a physical and electrical representation of the electric field sensor 1006. The conductive sense disk 1101 is positioned within the conductive cylinder 1002 such that it is effectively shielded from electric fields emanating from directions substantially off the sensor longitudinal axis. In this way, the electric field sensor 1006 achieves a substantial directivity to electric field vectors and may be effectively "aimed" in order to reduce the coupling effect of unwanted electric field sources. In actual use, the electric field sensor 1006 may be "pointed" towards earth ground to provide a signal proportional to and in phase with the actual line-to-earth potential while rejecting electric field vectors emanating from other sources. Alternatively it is conceived that the electric field sensor 1006 may be "aimed" at a second conductor in a three phase transmission arrangement in order to sense line-to-line potential although this as of yet has not been field proven.

[0090]     Environment Capacitor Ce 1107 is schematically shown to represent the effective coupling capacitance between the conductive sense disk 1101 and what is effectively the Earth's surface, objects in proximity, and "free-space" capacitance. Capacitor Ce 1107 represents an unknown variable and is dependent on the specific installation, size of conductive sense disk 1101, the position of the sense disk 1101 within the conductive cylinder 1002, and general field distortion due to electric field sensor geometry. A typical value for capacitor Ce 1107 would be significantly less than a pico-farad. Parasitic capacitor Cp 1108 schematically represents the total shunt capacitance between the conductive sense disk 1101, wire connection 1103, and inner conductive surfaces of the electric field sensor 1006. The conductive cylinder 1002 is bonded to the circuit common ground 1211 providing a common reference point for all internal electronics 1200.

[0091]     Capacitance Ce 1107 essentially forms a capacitive, high division voltage divider dominated by the parallel combination of Cp 1108 and binary weighted capacitor bank CB1 1201. Summing point S1 1202 represents the output of the divider, which is provided to the input of operational amplifier U5 1205. Operational amplifier U5 1205 may be of the ultra-high input impedance variety, providing minimum dc and reactive loading at summing point S1 1202. Operational amplifier U5 1205 operates as a high impedance unity gain buffer, the output of which is provided to interface connector J1 1004 for subsequent digital conversion and processing. A representative Operational Amplifier type would include the OPA340 manufactured by Texas Instruments of Dallas, Texas, U.S.A. High impedance resistor R30 1204 provides a +2.5 Vdc bias offset to the amplifier U5 1205 output. It is appreciated that other amplifier configurations, such as bipolar supply ground-referenced types, may be employed with similar results. Resistor R31 1206 limits transient current events from damaging operational amplifier U5 1205

and additionally works with capacitor C34 1207 to provide a low pass filter pole operable to remove high frequency signal components from the analog output signal 1208. Gas discharge arrester GR1 1203 may be provided for fast circuit protection in case of lightning or fault induced electric field transient events. The fast acting gas discharge arrester GR1 1203 has very low capacitance (< 1 pF) and high impedance below the clamping trigger point. Solid-state transient suppressors, such as MOV's, Transorbs, and Sidactors, may also be employed in a similar fashion though the particular protection circuit topology may change to accommodate these other devices.

[0092]     The capacitor bank CB1 1201 is shown having 4 bits of resolution comprised of capacitors C30, C31, C32, and C33 . The capacitor values are weighted in a binary fashion. For example, C33 might be 2nF, C32 would be 4nF, C31 would be 8nF, and C30 would be 16 nF. This provides a maximum capacitance value of 30nF with a LSB resolution of 2nF. The capacitor bank CB1 1201 is shown having individual electro-mechanical relay contact 1299 control and driven by a serial peripheral drive interface 1209. It is appreciated that other methods, including active solid-state analog switches, may be employed with similar results. An example of a solid-state switching system may be provided by using complimentary MosFet transistors such as provided by model SN74HC4066D manufactured by Texas Instruments. The measurement module 750, to which the electric field sensor 1006 is connected, can control the specific capacitive divider ratio through commands sent to the serial peripheral drive interface 1209. This allows the measurement module 750 to control the electric field sensor 1006 gain in response to varying electric field input levels. This allows a single electric field sensor 1006 to operate over a wide range (auto-range) of installed transmission line voltage (e_field) levels by adjusting the capacitive divider ratio such that the summing point S1 1202 voltage remains within the optimal dynamic range of the analog-to-digital conversion process.

[0093]     The digitally controlled binary weighted capacitor bank CB1 1201 may be used to calibrate the electric field sensor 1006 such that an accurate determination of high voltage current carrying conductor 810 to Earth (neutral) RMS AC potential may be made. Capacitors C30 through C33 are of a high accuracy and temperature stable variety. Possible types include polystyrene or polypropylene varieties. To achieve the highest accuracy, a factory measurement is made of capacitance as measured between the conductive sense disk 1101 and circuit common 1211 provided by the conductive cylinder 1002. The measurement is made by individually switching in capacitors C30 through C33 1210 through the serial peripheral drive interface 1209 under software control. The combined total voltage divider capacitance between summing point S1 1202 and circuit common 1211, including parasitic capacitance Cp 1108, is therefore quantified and able to be accurately selected under software control. The environmental capacitance represented schematically by Ce 1107 may be solved for using the following methodology which is also discussed in co-pending U.S. Patent Application Serial No 10/868,374, filed June 15, 2004, entitled "Non-Instrusive Power Monitor" which is herein incorporated by reference.

[0094]     The following discussion assumes that the electric field sensor 1006 is installed and operating on an energized high voltage conductor. The binary weighted capacitor bank 1201 can be switched to a first known capacitance C1 and the resulting V1rms voltage is then measured at the output of operational

amplifier U5 1205. Then, the binary weighted capacitor bank 1201 is switched to a second capacitance C2 and the resulting voltage V2rms at the output of operational amplifier U5 1205 is recorded. The environmental capacitance Ce 1107 can be calculated from the following formula when the voltage on the high voltage current carrying conductor 810 is approximately constant:

$$Ce = \left[ \frac{V1rms * C1 - V2rms * C2}{V2rms - V1rms} \right]$$ where:

[0095]    V1rms is the voltage measured across the capacitor bank 1201 when capacitor bank 1201 has a value of C1. The voltage across the capacitor bank 1211 at summing point S1 1202 is reproduced at the output (Vout 1208) of operational amplifier U5 1205.

[0096]    V2rms is the voltage measured across the capacitor bank 1201 when the capacitor bank 1201 has a value of C2.

[0097]    Thereafter, the voltage between transmission line 810 and Earth potential can be determined using the following formula:

$$V = Vout \left[ 1 + \frac{Ccb}{Ce} \right]$$ where:

[0098]    V is the voltage on transmission line 810.

[0099]    Vout 1208 is the output of the operational amplifier U5 1205 and is essentially a buffered version of the voltage across the capacitor bank CB1 1201 at summing point S1 1202

[00100]    Ccb is the capacitance of the capacitor bank CB1 1201 including the parasitic capacitance Cp 1108 which may be determined through factory calibration means.

[00101]    Ce is the environmental capacitance found through the calibration cycle as previously described.

[00102]    It will be appreciated that although a few examples of the invention incorporating the power supply module 108 have been presented and described, many more examples of HVTLAD 100 devices are possible. The following sections discuss additional examples that have been conceived.


MESH NETWORK

[00103]    A mesh network can be formed by mounting multiple HVTLADs 100 along a transmission line and on different transmission lines within appropriate proximity. Each HVTLAD 100 has an RF data link transceiver 69 which can communicate with adjacent HVTLADs 100. With appropriate gateways to other networks, such as the Internet or an intranet, the HVTLADs 100 may provide for communication links across geography which may not already have such links.


DRONE

[00104]     By mounting appropriate mechanical and/or robotic hardware to the HVTLAD 100, the HVTLAD 100 may be made operative to traverse the power line. For example, powered wheels may be mounted to the HVTLAD 100 and the HVTLAD 100 may no longer be clamped to the power line. The wheels may be appropriately attached to the power line and using the power provided by power supply module 108, electric motor(s) may be driven to move the HVTLAD 100 along the power line. The drone HVTLAD 100 may be equipped with a video camera and thus be used to traverse the power line looking for faults in the line, insulators, towers, etc. or for general video surveillance. The drone HVTLAD 100 may also or alternatively be equipped with a vibrating motor, electronically driven hammer, etc. operative to vibrate or impact the power line at a given point in order to dislodge ice.

DISPLAY

[00105]     The HVTLAD 100 may be equipped with a display such as an LED, LCD, etc. The display may be powered from the power supply module 108. The display may be used to display advertising to persons near the HVTLAD 100. Other displays include highway information signs, "Amber" alert messages etc. The display functionality of the HVTLAD 100 may be combined with the drone functionality to create a moving display.

OTHER POWER SOURCES

[00106]     Complementing the power supply module 108, the HVTLAD 100 may have complimentary power sources such as solar panels, wind turbines, etc. When additional power is available from these sources, additional functionality of the HVTLAD 100 may be enabled.

SATELLITE/PLC LINKS

[00107]     In addition to the GPS receiver, the HVTLAD 100 may comprise additional satellite communication transceivers. In addition or alternatively, the HVTLAD 100 may comprise a power line carrier transceiver. These may enable the transmission or reception of sensor or other data (such as advertising content or drone movement directions).

RADAR WARNING

[00108]     The HVTLAD 100 may comprise a transmitter or transceiver operative to trigger an aircraft's radar. This may be useful when fog or other obstructions prevent the pilot of the aircraft from seeing the light emitted by the HVTLAD 100. In addition, the HVTLAD 100 may transmit warning tones on various RF frequencies for the same purpose.

ANALOG RADIO

**[00109]**     Although as described above, data indicative of voltage, current, power, etc. may be transmitted in digital form, this data may also be transmitted in analog form from the HVTLAD 100 to a local receiving station 920.

FIBER REPEATER

**[00110]**     In new installations, it is common that transmission lines have fiber optic cables within them. The HVTLAD 100 may be used as a fiber optic repeater. The fiber optic signal may enter the HVTLAD 100 within the transmission conductor 10 as shown in Fig. 1 and be amplified by appropriate circuitry within the HVTLAD before exiting the HVTLAD 100.

ADDITIONAL SENSORS

**[00111]**     The HVTLAD 100 may alternatively or in addition be supplied with other sensors. A first example of an additional sensor is a temperature sensor operative to determine the temperature of the power line. This sensor may use infrared technology and may provide an indication of overheating of the power line. A second example of an additional sensor is a vibration or acceleration sensor. This sensor may provide an indication of stress on the power line from wind, ice, earthquake, impact, etc. A third example of an additional sensor is strain or tension sensor operative to sense the tension within the power line. This may also be an indication of stress on the power line. A fourth example of an additional sensor is a humidity sensor. Humidity may be used as a parameter in determining the current carrying capacity of the power line. A fifth example of an additional sensor is an air quality sensor. This sensor may be used generally to provide information to a remote site or may be used in estimating the affect of air impurities on the power line (due to corrosion, etc.). A sixth example of an additional sensor is a sound sensor. This sensor may be used to provide information to a remote site of local sound level. A seventh example of an additional sensor is an atmospheric pressure sensor operative to provide such information to a remote site for various purposes.

**[00112]**     It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to define the spirit and scope of this invention.